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PROWERSOSE (SYENITIC LAMPROPHYRE) FROM TWO BUTTES, COLORADO[1]

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In 1896 G. K. Gilbert[2] described in this *Journal* the laccoliths occurring at Two Buttes, in the Arkansas valley, near the eastern border of Colorado and about 150 miles from the mountain front at Canyon City. The igneous rocks of this locality, embracing specimens from two laccoliths and many associated dikes, were submitted to me for determination, but no detailed descriptions have as yet been published. The interest attaching to the principal rock type and some of its associates made a renewed examination of their field-relationships desirable, and such a study is contemplated for the field season of the current year.

The rock of the larger laccolith at Two Buttes possesses an unusual mineral composition, and it was subjected to chemical analysis by W. F. Hillebrand. The analysis, which was published, with a brief description by myself, in the well-known compilation of rock analyses made in the U. S. Geological Survey laboratory,[3] has led to the classification of the rock by the quantitative system in a subrang without other known representatives until the one described by Mr. Bastin in the accompanying paper was discovered. The rarity of such rocks, and the fact that the one from Colorado

[1] Published with the permission of the Director of the U. S. Geological Survey.

[2] "Laccolites in Southeastern Colorado," *Journal of Geology*, Vol. IV, pp. 816–25.

[3] "Analyses of Rocks," tabulated by F. W. Clarke, *Bulletin No. 228* (1904), U. S. Geological Survey, p. 186.

has received practically no petrographic discussion, make its description at this time appropriate, although nothing can as yet be added to the general statement of occurrence given by Gilbert, which is summarized below.

Features of occurrence.—The rock forms the lower of two laccoliths, of an extent not clearly determinable, owing to surficial gravels. The horizons of intrusion of the known masses are in Triassic Red Beds, but a few hundred feet below Cretaceous strata. The lower Cretaceous beds are upturned about the laccolith, and Gilbert considers it probable that the intrusions occurred either in "the closing epochs of the Cretaceous or the earlier half of the Eocene." The outcrop of the rock to be described "is nearly continuous for three-fourths of a mile from north to south and more than half a mile from east to west." While it is not desired to present details of occurrence here, it may be noted that Gilbert observed some fifty dikes traversing the sediments of horizons above that of the laccoliths, and that many of these dikes belong to the type under discussion. The upper and probably smaller laccolith, separated from the lower one by a few feet of limestone, is composed of very similar material.

General description.—The rock of Two Buttes submitted to analysis is fine-grained, greenish-gray, with a habit sometimes exhibited by minette. Its most prominent megascopic constituent is biotite, occurring in glistening brown, hexagonal plates 2^{mm} or less in diameter, with a few blades 1^{cm} long. There are a few reddish-brown phenocrysts, 2 or 3^{mm} in length, representing original olivine, now wholly replaced by serpentine and chlorite, and colored by iron oxide.

A hand lens reveals many prisms of pale-green augite, and an abundance of feldspar is evidently present as interstitial material. A few aggregates of feldspar grains are scattered irregularly through the mass, but there are no normal phenocrysts. The lens also shows many minute pores, but the rock is so fresh that these seldom contain secondary minerals. The fractured surface is rough or hackly.

Microscopic characters.—Under the microscope this rock is found to consist essentially of a feldspathic base holding, besides the mega-

scopic phenocrysts, many small biotite leaves, augite grains and prismoids, and a multitude of minute magnetite grains. There is a gradual transition from the minute biotite and augite individuals to those 2 or 3^{mm} in diameter—a feature which causes the porphyritic texture to be subordinate and crude.

Feldspar is the most abundant constituent, and it seems to be wholly orthoclase, occurring in ill-defined scales or tablets which are characteristically arranged, and possibly intergrown, in sheaf-like, imperfectly radial groups. There are no sharply defined crystals, and the maximum dimension of the particles is perhaps $\frac{1}{5}^{mm}$. Because of the great number of other mineral grains which are held by this orthoclase mass, and through the presence of many minute dustlike interpositions, the feldspathic constituent can be satisfactorily studied only in certain small areas scattered through the rock, where the femic minerals are quite subordinate.

All feldspar on the borders of the sections has a lower index of refraction than the Canada balsam, no multiple twinning has been observed, and the analysis of the rock shows that a soda feldspar is not likely to be present. Probably the orthoclase contains a small amount of the albite molecule.

Biotite is quantitatively the next constituent of importance. It occurs in scales which are seldom crystallographically bounded, the large phenocrysts and some of the smallest flakes being the prominent exceptions. The pleochroism ranges from pale yellow to a reddish brown. It is clear that the mineral is poor in iron. It is quite fresh throughout the rock.

The pyroxene occurs in prismoids, colorless or faint green as a rule, but some of the stouter prisms contain a core of bright grass-green color. The clino-pinacoidal extinction in such cases is about 36° for the green core and 45° for the outer zone. The pyroxene, being fresh and very nearly free from inclusions, was isolated and analyzed by Dr. W. F. Hillebrand, with the result given in Column II of the table, p. 168. Its specific gravity is 3.45 at 25° C.

This pyroxene is a strongly diopsidic augite, and by assuming the Fe_2O_3 to be about one-half too high, the mineral may be calculated to have the composition: 6 Na_2 Fe_2 Si_4 O_{12} (aegirite) + 34 (Na_2R) $(Al\ Fe)_2$ SiO_6 + 403 Ca (Mg Fe) Si_2O_6 (diopside). It is

unusually high in alumina for the augite of a rock with potash strongly predominant over soda.

TABLE OF CHEMICAL ANALYSES

	I	II	III	IV	V	VI	VII
SiO_2	50.41 0.840	51.27 0.855	1.58	52.26	56.39	57.31	51.75
Al_2O_3	12.27 0.121	3.05 0.029	1.00	10.63	12.88	14.71	14.52
Fe_2O_3	5.71 0.036	3.08 0.019	None	2.47	2.36	1.21	5.08
FeO	3.06 0.045	4.34 0.061	0.87	5.45	3.54	4.37	3.58
MgO	8.69 0.217	14.21 0.355	1.22	9.32	7.83	7.80	4.55
CaO	7.08 0.128	22.58 0.403	0.68	5.62	4.06	6.90	7.04
Na_2O	0.97 0.016	0.67 0.011	Undet.	1.60	1.30	1.35	2.93
K_2O	7.53 0.080	0.06	Undet.	5.99	7.84	6.38	7.61
$H_2O - 110°$	0.46	None	None	0.98	1.33	0.18	2.25
$H_2O + 110°$	1.80	Undet.	Undet.	1.97	....	....	....
TiO_2	1.47	0.70	....	1.92	2.07	0.40	0.25
ZrO_2	0.019	0.009	....	0.08	....	....	...
CO_2	....	....	....	0.75	....	....	....
Cl	....	....	....	....	....	....	0.05
P_2O_5	0.46 0.003	....	0.46	0.98	....	....	0.18
V_2O_3	0.03	....	....	....	....	....	....
NiO	0.04	0.03	....	....	....	....	....
MnO	0.15 0.002	0.28 0.004	Trace	0.12	....	...	Trace
BaO	0.23 0.002	None	None	....	...	....	0.30
SrO	0.06	None	?	....	....	....	0.07
	100.42	100.27	5.81	100.14	99.60	100.61	100.14

I. Prowersose (syenitic lamprophyre), Two Buttes, Colo.; W. F. Hillebrand, analyst.

II. Augite from I; W. F. Hillebrand, analyst.

III. Portion of I soluble in dilute nitric acid (1:40).

IV. Prowersose (syenite porphyry), Knox county, Maine. George Steiger, analyst.

V. Ciminose (selagite); Monte Catini, Tuscany; H. S. Washington, analyst; *American Journal of Science*, Vol. IX (1900), p. 47.

VI. Ciminose (ciminite), La Colonetta, near Viterbo, Italy; H. S. Washington, analyst; *ibid.*, p. 44.

VII. Fergusose (fergusite), Highwood Mountains, Montana; E. B. Hurlburt, analyst; *Bulletin No.* 237, U. S. Geological Survey, p. 86.

The microscope shows the presence of serpentine and chlorite occupying areas which probably represent original crystals of olivine. Some are large, corresponding to those seen in the hand specimen, while others are very small. The alteration is so extreme, however, that neither by outline nor by indications of the course of alteration can one positively determine this matter.

Magnetite occurs in very numerous particles only 0.01^{mm} to 0.02^{mm} in diameter, and apatite is chiefly developed in minute needles, with here and there a large stout phenocryst, comparable to the augite in size.

The obscure character of the salic constituents led to a careful search for leucite and nephelite, without evidence of either being found. The 5.81 per cent. of the rock soluble in dilute nitric acid contains no appreciable soda, and hence nephelite and zeolites derived from it are excluded.

On the basis of the above description, this rock may be called, in the prevailing nomenclature, a syenitic lamprophyre allied to minette.

The rock contains some small angular and sharply defined inclusions of white color and fine granular texture, which are seen in thin section to consist mainly of orthoclase and very obscure microperthite, with possibly a small amount of some highly sodic plagioclase. These minerals are developed in anhedral grains, and resemble the orthoclase of the rock only in their dustlike interpositions. A few flakes of biotite, prisms of augite, and grains of magnetite larger than those of the rock are scattered through this feldspathic mass. It seems to represent material genetically related to the host, but derived from some deep-seated source. There is no suggestion of fusion or assimilation of the included particles.

Classification by the quantitative system.—The norm of the Two Buttes lamprophyre is given in Column I of the accompanying table. For comparison the norms of the other rocks of which analyses have been given are appended. The figures for IV are taken from Bastin's paper; for V and VI, from Washington's tables; and for VII, from Pirsson's bulletin on the Highwood Mountains.

The position of the Two Buttes rock in the quantitative system

TABLE OF NORMS

	I	IV	V	VI	VII
Salic molecules—					
Quartz			1.0		
Orthoclase	44.5	35.6	46.1	37.8	45.0
Albite	3.9	13.6	11.0	11.5	3.7
Anorthite	6.9	3.9	6.0	15.0	3.9
Nephelite	2.4	....	....	....	11.4
Femic molecules—					
Diopside	20.1	13.9	11.1	15.3	23.8
Hypersthene	....	15.0	15.6	16.2	....
Olivine	8.7	4.9	....	1.8	1.5
Magnetite	6.0	3.4	3.5	2.2	7.2
Ilmenite	2.9	3.6	....	....	0.5
Hematite	1.6	....	....	....	....
Apatite	1.0	2.3	....	....	0.3

I. Prowersose, Two Buttes, Colo.
IV. Prowersose, Knox County, Maine.
V. Ciminose, Monte Catini.
VI. Ciminose, La Colonetta.
VII. Fergusose, Highwood Mountains.

is shown, by the subjoined analysis of its norm, to be in the subrang *prowersose* (III, 5, 2, 2).

$$\frac{\text{Sal}}{\text{Fem}}=\frac{57.8}{40.3}=1.43<\frac{5}{3}>\frac{3}{5}=\text{Class III, } \textit{Salfemane.}$$

$$\frac{\text{L }(ne)}{\text{F }(or+ab+an)}=\frac{2.4}{55.3}<\frac{1}{7}=\text{perfelic order (5), } \textit{gallare.}$$

$$\frac{K_2O'+Na_2O'}{CaO'}=\frac{80+16}{25}=3.8<\frac{7}{1}>\frac{5}{3}=\text{domalkalic rang (2), } \textit{kilauase.}$$

$$\frac{K_2O'}{Na_2O'}=\frac{80}{16}=5<\frac{7}{1}>\frac{5}{3}=\text{dopotassic subrang (2), } \textit{prowersose.}$$

The *prowersose* from Maine, while lower in salic molecules than that from Colorado, is so much richer in normative orthoclase and albite as compared with anorthite $\left(\frac{K_2O'+Na_2O'}{CaO'}=\frac{90}{14}\right)$ that it approaches the peralkalic rang *orendase*. But its ratio of potash to soda is lower than for the Colorado rock; hence it does not come so near to the perpotassic *orendase* as does the latter. There is no known member of the dopotassic subrang of *orendase* with which the *prowersose* may be compared.

By consulting Washington's tables it will be seen that the only other salfemanes possessing high potash greatly in excess of soda

are the peculiar leucite rocks of the Leucite Hills, Wyoming, orendite and wyomingite. These are, however, so extremely rich in potash that they fall within the peralkalic rang of the gallares and in its perpotassic subrang, *orendase*. Hence they are farther removed from *prowersose* than are other rocks of which analyses are given in the table.

The rock of Washington's tables within the rang *kilauase* which comes nearest to *prowersose*, belongs to the sodipotassic subrang *lamarose*. It is a leucite-absarokite of Yellowstone Park, but in the low total of alkalis (K_2O 3.79 per cent. Na_2O 1.88 per cent.) and in the high magnesia contents (15.96 per cent.) this rock differs so markedly from the *prowersose* that further comparison seems unnecessary.

On the whole, the nearest relatives of the *prowersose* described are two rocks of the Italian province, belonging to the corresponding subrang of the Dosalane class—namely, *ciminose* (II, 5, 2, 2). These rocks, while notably richer in the albite molecule, maintain a strong preponderance of orthoclase.

Another rock with which comparison is particularly interesting is the unique *fergusose* (II, 6, 2. 2), described by Pirsson from the Highwood Mountains. This rock is very near the *prowersose* of Two Buttes in normative orthoclase, albite, and anorthite, but it is so rich in normative nephelite as to be brought within the lendofelic order (6) of the Dosalane class. The close chemical relationship evident in the analyses is made plain systematically by observing that, if somewhat less than 4 per cent. of normative nephelite of this *fergusose* were replaced by any femic molecule, it would be changed to *prowersose*. It may be noted that there is as yet no known rock of the Salfemane class corresponding to *fergusose* in its chemical relations.

Modal characteristics of the rocks compared.—The *prowersose* of Two Buttes clearly belongs to one of the rock groups illustrating the fact, not yet sufficiently recognized among petrographers, that there may be important variations in the mode or actual mineral composition of igneous rocks possessing very similar chemical composition. The most notable variation in this particular group is in the development of biotite on the one side, and leucite (or ortho-

clase) and olivine on the other. That this variation is in large degree dependent on geological occurrence as influencing conditions of consolidation has been pointed out, notably by Iddings[1] and Washington,[2] the latter while discussing the rocks of Monte Catini and La Colonetta of which analyses have been given.

The rocks of the above tables are all intrusive, except the ciminite of La Colonetta, which is a surface flow. The latter is the only one in which biotite is not an important constituent. It contains numerous phenocrysts of augite and olivine, with a few of orthoclase and labradorite in a very dense groundmass, which is "a felt of minute orthoclase and some labradorite laths lying in a glassy base" (Washington).

On the other hand, the selagite or mica-trachyte of Monte Catini has very closely the habit of the Colorado *prowersose*, as I am able to state through examination of a type specimen donated by Dr. Washington to the Petrographic Reference Collection of the Geological Survey. The development of biotite and the megascopic appearance of the groundmass is very nearly the same in the two rocks. Microscopically, the difference in texture is more pronounced, as in the selagite augite occurs in small crystals forming a part of the groundmass, and the orthoclase tables are much more sharply defined than in the Two Buttes rock.

In marked contrast with the syenitic lamprophyre of Two Buttes stands the fergusite or pseudoleucite-syenite of the Highwood Mountains. That rock contains numerous pseudoleucite grains 5^{mm} or less in diameter, held in a matrix consisting chiefly of augite, with small amounts of biotite, olivine, and other accessory minerals.

The great textural difference between the two known types of *prowersose* is most striking. The rock of Knox County, Maine, is a most pronounced porphyry, as a reference to the description by Mr. Bastin, and a glance at the photographic illustration, will show. There are many large alkali feldspar phenocrysts lying in a groundmass of biotite and green hornblende.

[1] J. P. Iddings, "The Origin of Igneous Rocks," *Bulletin of the Philosophical Society of Washington*, Vol. XII (1892), pp. 176, 177.

[2] H. S. Washington, "Some Analyses of Italian Volcanic Rocks," *American Journal of Science*, Vol. IX (1900), p. 49.